CERAMICS

Outline

- Basic properties
- Crystalline ceramics
- Glasses
- Carbon ceramics
- Mechanical failure of ceramics
- Creep resistance
- Ceramics fabrication

Recall:

- Ceramics are chemical compound or solutions that consist of both metallic and nonmetallic elements
- Bonding can range from ionic to covalent.

In general, ceramics:

- have a high melting point
- have low electrical and thermal conductivity
- have good chemical and thermal stability
- are hard
- have high compressive strengths
- are brittle
- are creep resistant

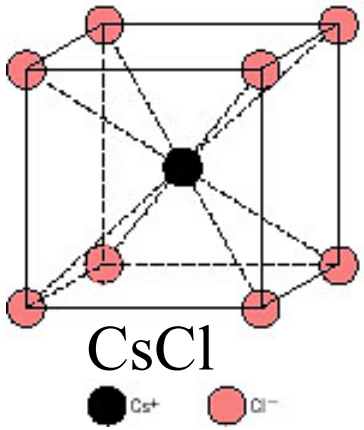
Crystalline ceramics

Structural difference from metals:

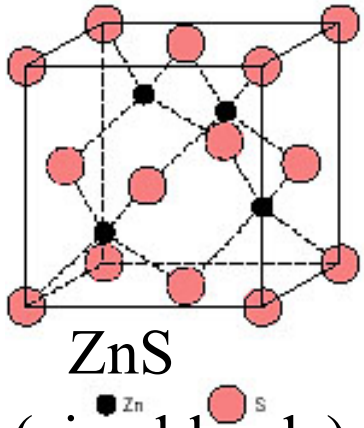
- ionic bond between two components
- components are considered ions (anions/cations)
- charge neutrality (electroneutrality) must be maintained
- electroneutrality is an added constraint on structural arrangement

Crystalline ceramics

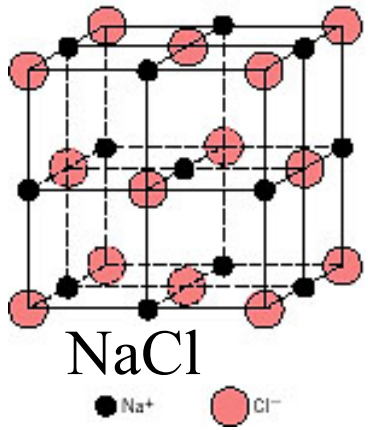
- Crystal structures of ceramics are more complicated than metals.



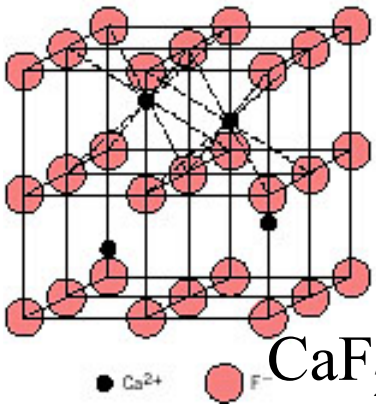
CsCl



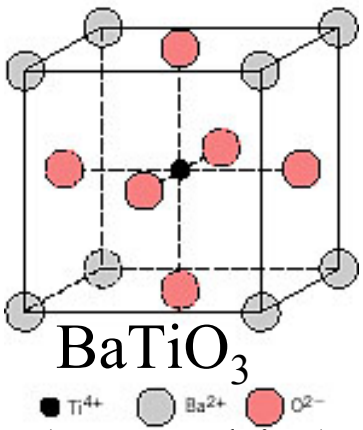
ZnS
(zinc blende)



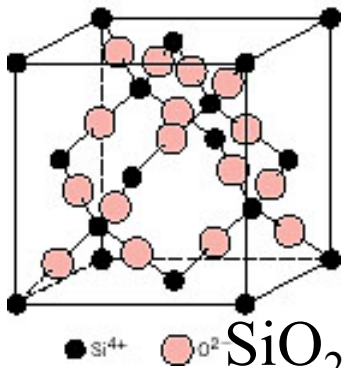
NaCl
(rock salt)



CaF_2
(flourite)



$BaTiO_3$
(perovskite)

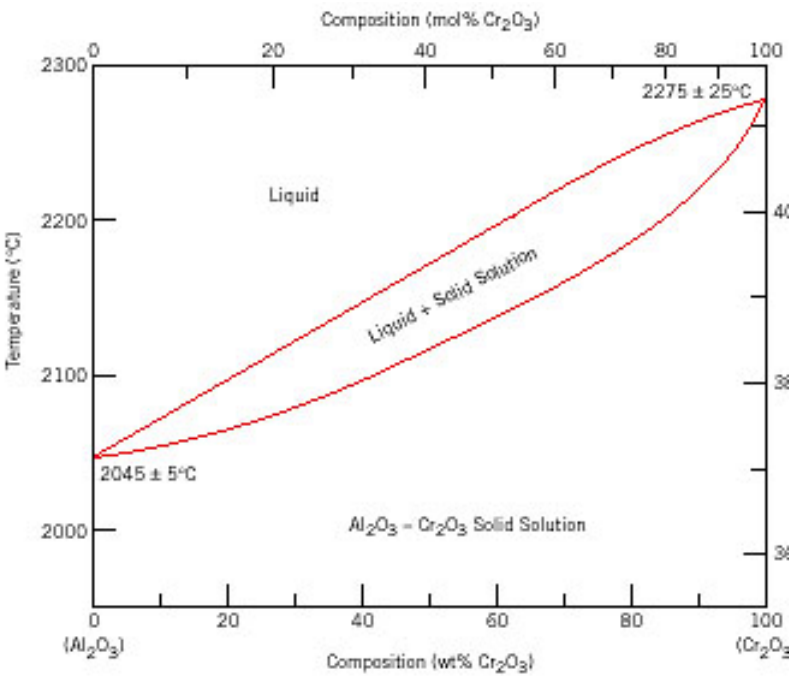


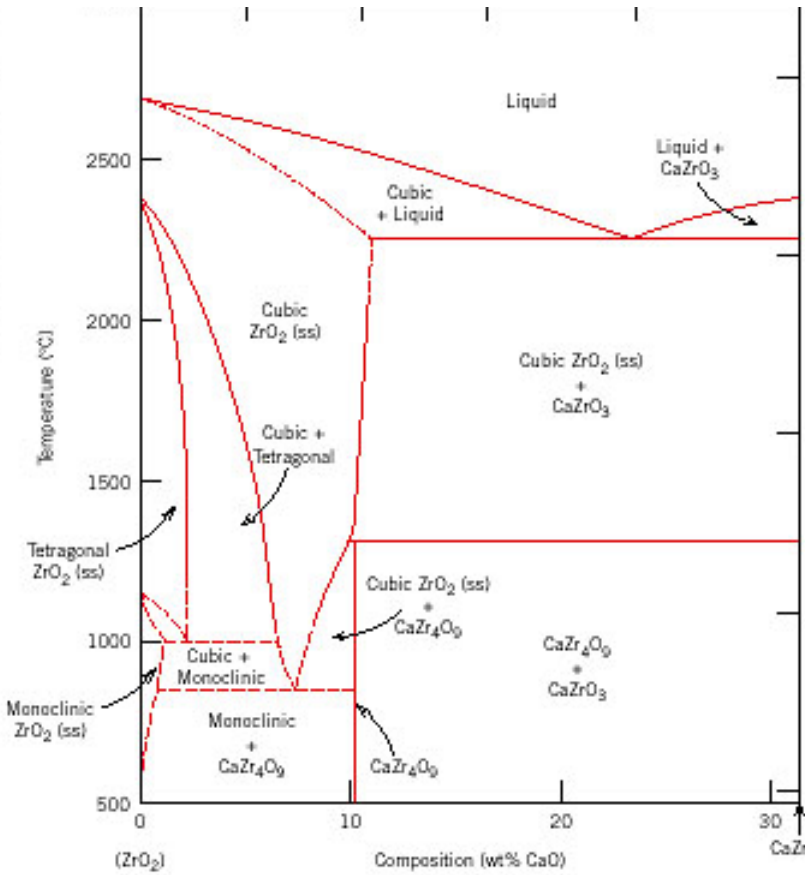
SiO_2

corundum (Al_2O_3)
spinel (Fe_3O_4)
graphite

Crystalline ceramics

- Interstitial and substitutional solid solutions can form with impurities or between two ceramics.

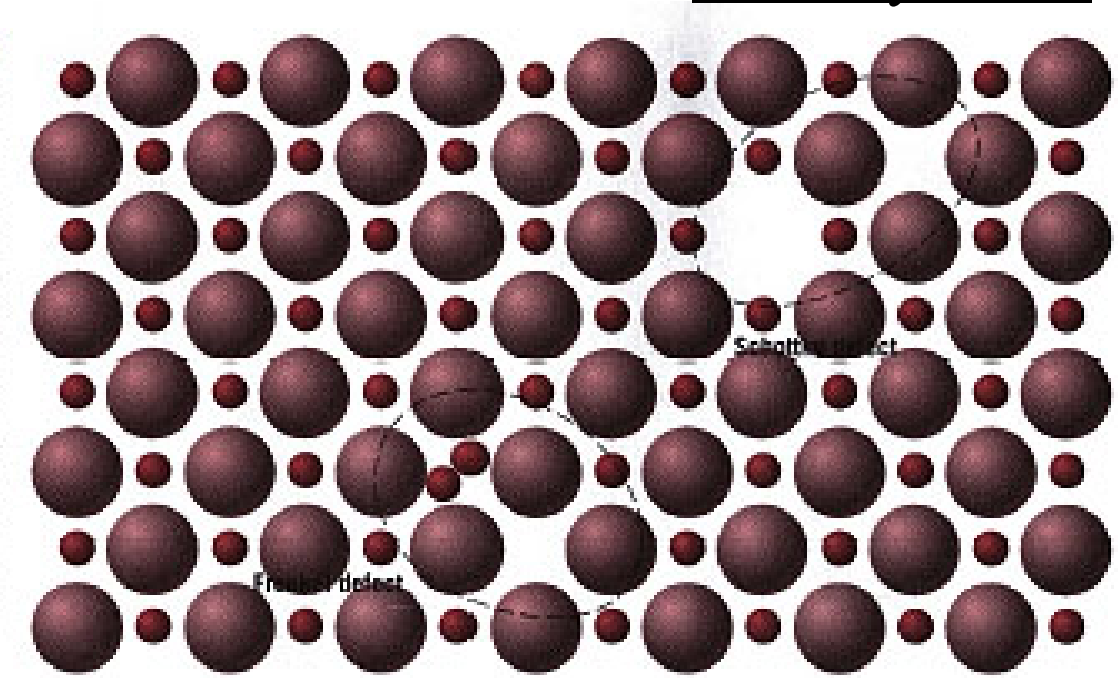




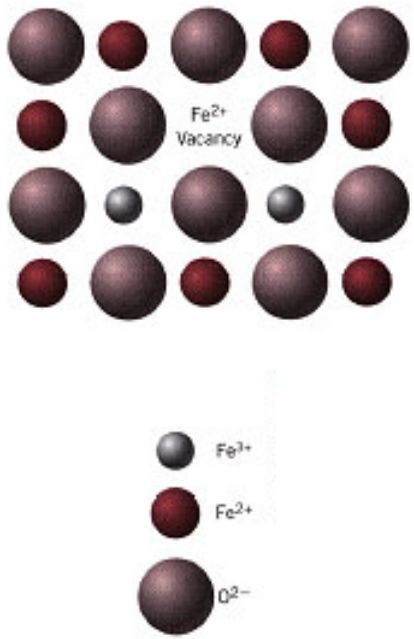
Point defect structures in crystalline ceramics

Because electroneutrality must be maintained, point defects do not occur alone.

Schottky defect

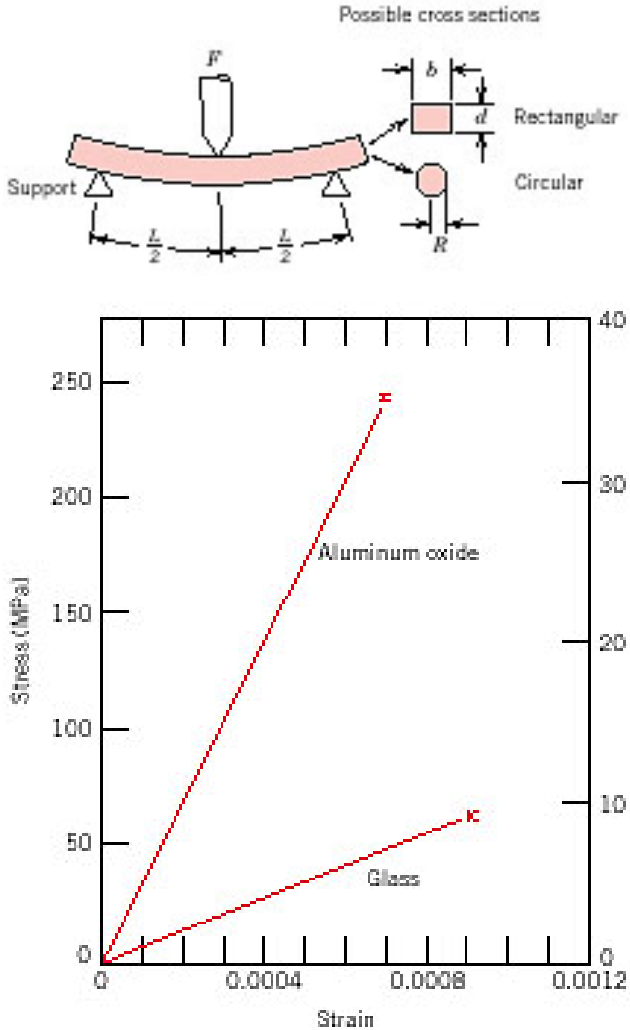


Frenkel defect

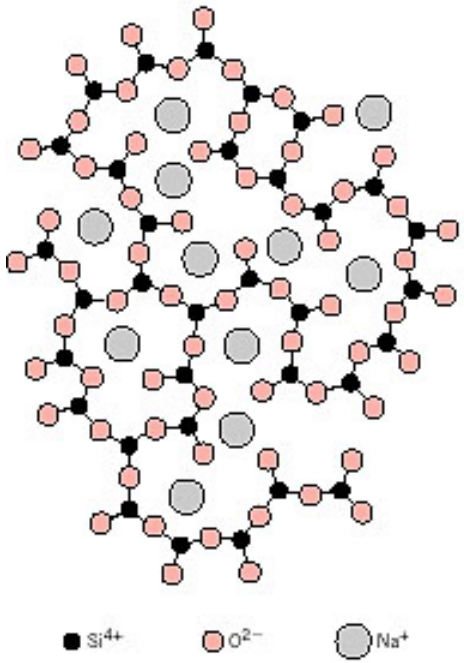


Deformation of crystalline ceramics

- Due to the requirement of electroneutrality, dislocation structures are complicated (if they exist at all) and are difficult to move.
- Result: ceramics are hard and brittle
- Recall the flex test $\Rightarrow$



Deformation of ceramic glasses (silicates)

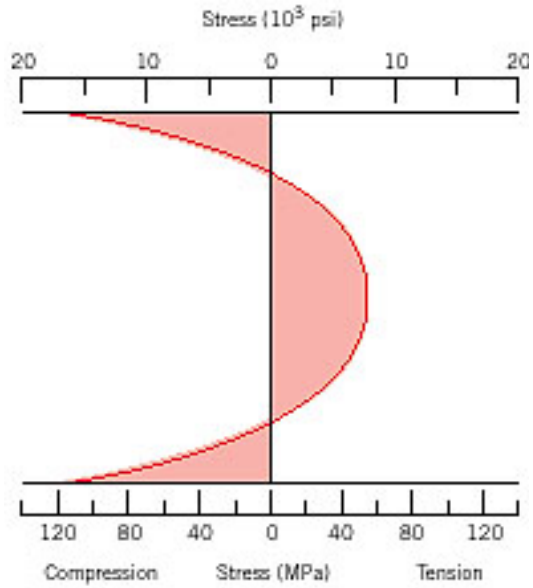


Typical soda-lime glass: 70 wt.% SiO_2 bal Na_2O (soda) + CaO (lime)

- Glasses are <u>amorphous.</u>
- Bonding is covalent in nature
- No crystal structure therefore, no dislocations.
- Glasses deform by <u>viscous flow</u>, like a liquid – ions slide past one another by the breaking and reforming of interatomic bonds
- Sodium is added as a <u>modifier</u> to reduce viscosity and make it possible to form glass at a lower temperature.

More about glasses

- Slow cooling is required to avoid thermal stresses or shock.
- Glasses can be strengthened by inducing compressive surface stresses.
- Process is called <u>thermal tempering</u>:
  - ➢glass is heated to just above T_g and cooled to RT by a jet of cool air
  - ➢surface becomes rigid before interior, interior wants to contract as it cools but can't, inducing compressive stresses on surface.

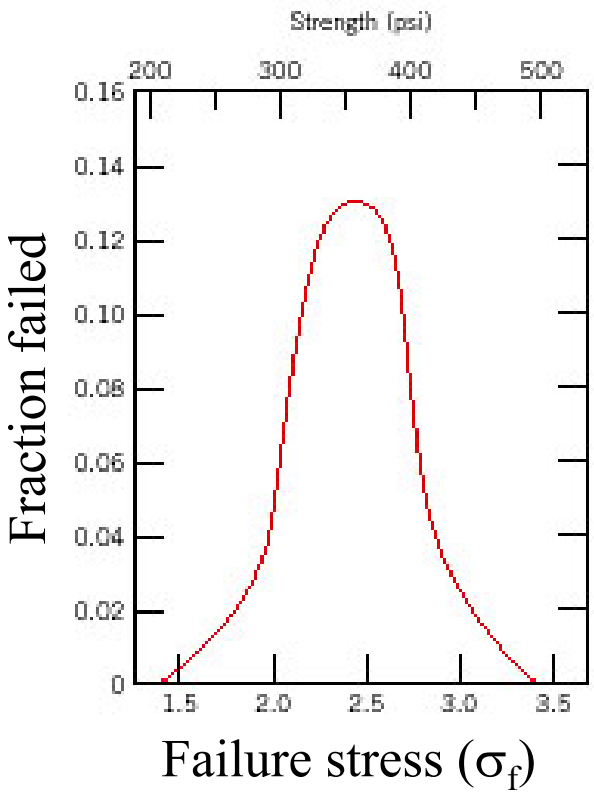


Mechanical failure of ceramics

- Ceramics are very brittle and defect sensitive. Failure is controlled by the presence of flaws.
- From a fracture mechanics standpoint, the critical flaw size for ceramics is very small.
- Manufacturing of brittle ceramics is driven by minimization of flaw size and quantity.
- The toughness of a ceramic is usually treated statistically.

Mechanical failure of ceramics

- Failure is often statistically described by a Weibull distribution.



$$\ln\left[\ln\left(\frac{1}{1-P}\right)\right] = m\ln(\sigma_f)$$

P=cumulative probability of failure

m=Weibull modulus

Desirable: a narrow distribution (which results in a large value of m)

m = 10-20 is typical for an advanced ceramic

Creep resistance in ceramics

- Diffusivity is slow in ceramics so creep resistance is higher than in metals.
- Creep in ceramics usually occurs due to grain boundary sliding.
- Creep resistance is improved by:
  - increasing grain size
  - decreasing porosity
  - decreasing impurities (which decreases viscous flow in glasses)

Comments on ceramic fabrication

- Ceramics cannot be fabricated by conventional metal forming techniques due to their mechanical and thermal properties.

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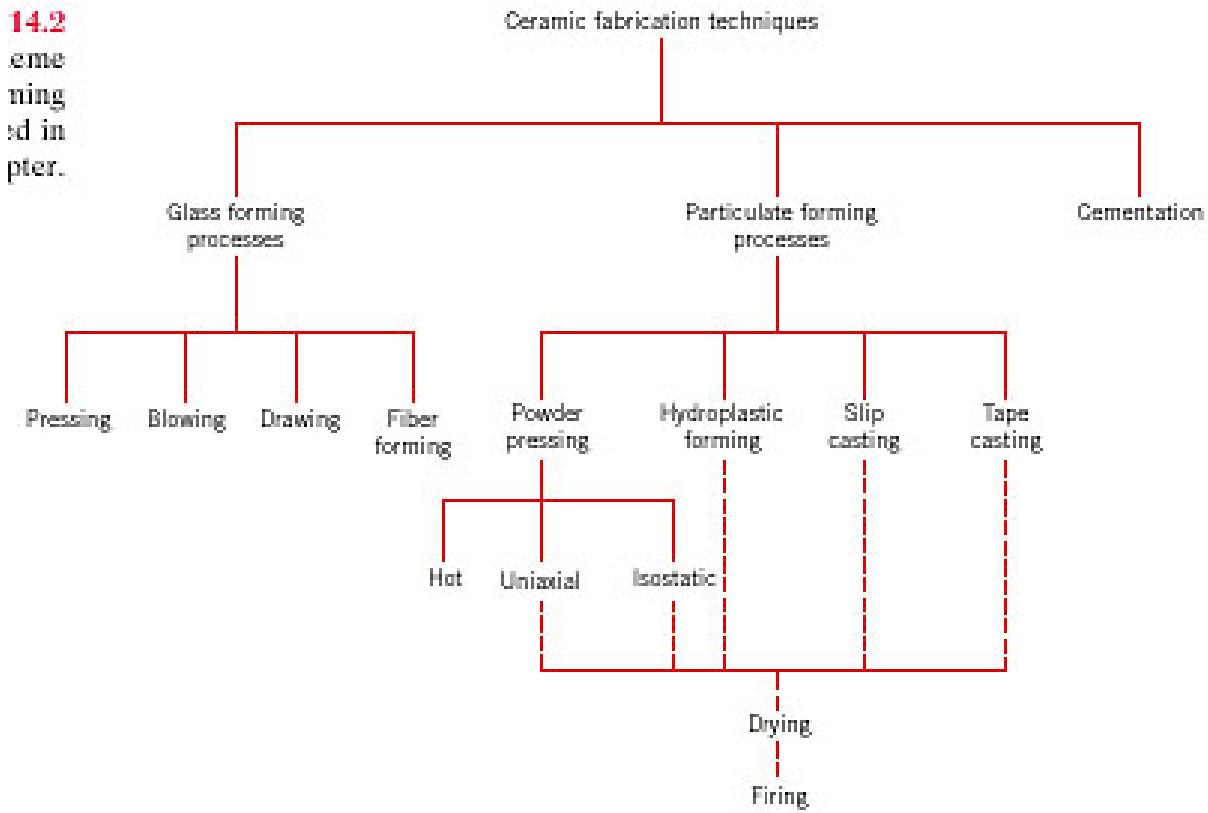
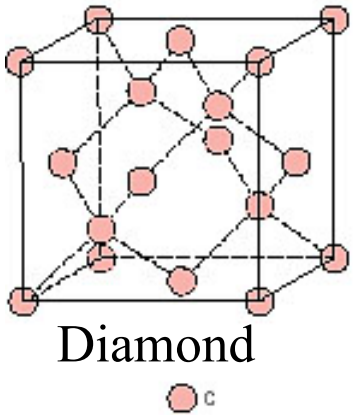
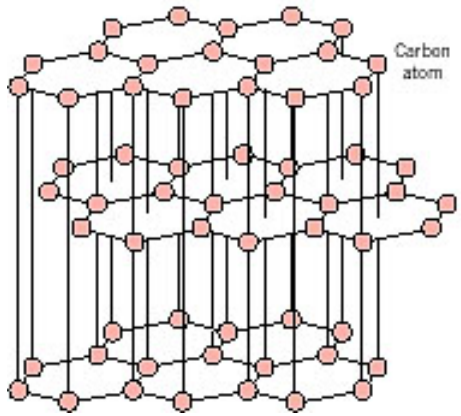


Carbon ceramics



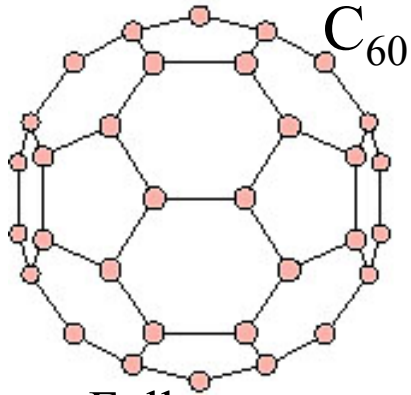
Diamond

- hardest material
- low electrical conductivity
- high thermal conductivity
- high index of refraction



Graphite

- thermally and chemically stable
- high thermal conductivity
- low thermal expansion
- high resistance to thermal shock
- excellent lubricity
- machinability



Fullerenes

- electrically insulating
- can be made highly conductive with impurity additions